Remote Heart Rate Sensing and Projection to Renew Traditional Board Games and Foster Social Interactions

Jérémy Frey

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Figure 1: A board game session that we augmented with remote physiological monitoring and projection.

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Abstract
While physiological sensors enter the mass market and reach the general public, they are still mainly employed to monitor health – whether it is for medical purpose or sports. We describe an application that uses heart rate feedback as an incentive for social interactions. A traditional board game has been "augmented" through remote physiological sensing, using webcams. Projection helped to conceal the technological aspects from users. We detail how players reacted – stressful situations could emerge when users are deprived from their own signals – and we give directions for game designers to integrate physiological sensors.

Author Keywords
Heart Rate; Social Presence; Board Games; Physiological Computing; Spatial Augmented Reality

ACM Classification Keywords
H.1.2 [User/Machine Systems]: Human information processing; H.5.1 [Multimedia Information System]: Artificial, augmented, and virtual realities

Introduction
Through the rise of wearables – such as smartwatches – physiological sensors are gaining increased attention. However, for the general public, the range of use-cases of such sensors seems mostly limited to health and performance. More often than not, physiological sensing is experienced within medical or sports settings only. Heart rate belts, for

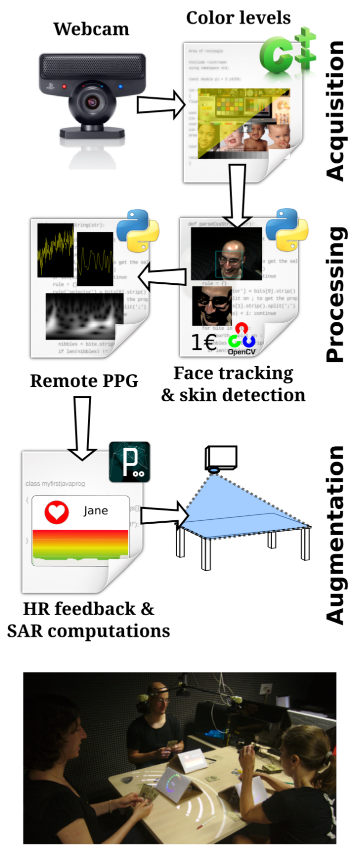

Figure 2: The pipeline composing our system.

example, are sold in many sports shops across the globe to help sportspeople boost their performance.

Physiological sensors can bring more to society. Lately, they have been investigated as a supplementary communication channel. A study showed that heartbeats were a meaningful source of information that could help people to "connect" between each others [13]. In the recent years, sensors have been used to mediate affect [15], to support social interplay [14] or to enhance telepresence [10].

Our work is part of the same movement, that tries to leverage social interactions among peers with physiological computing. Indeed, such information could help to create deeper interactions [6], enriching social presence – that relates to the degree of salience of another person [12]. We focus on playful and casual interactions, because it is also an opportunity to foster the *use* of physiological sensors among the general public. To do so, we propose to integrate heart rate sensing to a traditional board game.

In the present work we used projection to display information. It is less likely to disrupt the gaming experience than relying on screens because the projected content can be integrated seamlessly to the environment. Indeed, spatial augmented reality (SAR, introduced in [11]) brings digital content to the physical world and thus facilitates the merge between computers and existing board games (Figure 1).

Furthermore, as opposed to sensors attached to the body, we relied on a non-contact system to record heart rate by the mean of photoplethysmographiy (PPG). It uses webcams to process subtle variations in skin's color while blood is flowing. To our knowledge, this is the first time that remote sensing is used for several users, in a social context.

Using SAR and PPG, the technology disappears in the eyes of the players, keeping the genuine "feel" of traditional board games. But then we need to ensure that such addition does not hinder user experience and that sharing an information that usually belongs to the realm of the self does not deter how users feel. Some may not like that others see "through" them, especially when heartbeats may relate to intimacy [6]. In particular, this negative effect may be more likely to arise if the situation between players is not perceived as being "fair", e.g. if the biofeedback is seen by others and *not by the one being measured*.

Our first hypothesis is that the presence of a biofeedback equally shared between players – i.e. a heart rate visible by all – will improve game experience and social presence. Our second hypothesis is that an *asymmetrical* biofeedback – i.e. players see opponents' heart rate but not their own – will on the contrary cause more stressful situations and *deter* game experience.

In order to test these hypotheses, we used the versatility offered by SAR to create three different biofeedback conditions: heart rates visible by all, heart rates visible by others but not by self, no heart rates displayed.

The main highlights of this paper are:

1. To integrate seamlessly physiological computing into a traditional board game
2. To investigate how biofeedack influences user experience and social interactions

Related work

Even though previous works combined physiological monitoring and board games, they did not focus on how users reacted to this new feedback – nor did they consider the benefits for board games in general. For instance, [13] investigated how people comprehend heart rate feedback in various situations, and the appearance of a gaming application among users was incidental. The biofeedback was

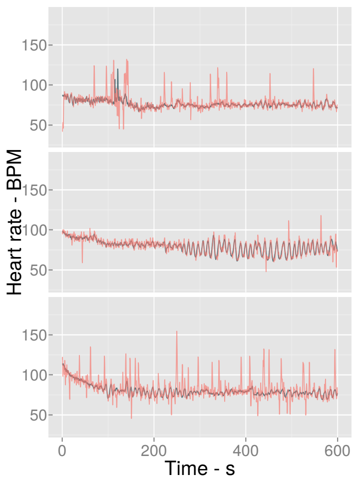

Figure 3: Separate study to validate remote PPG: heart rate measures over 3 recording sessions of 10 minutes. Remote PPG is represented in red, the ground truth (ECG) in black. Average Pearson correlation: 0.53. Remote PPG is accurate enough to account for the heart rate variability caused by deep breathing – e.g. oscillations in session 2, *middle*. Each session was preceded by 5 minutes of aerobic exercise. See [4] for more details.

studied for training in [16] as a way to help poker players gain control over themselves. Another combination of poker and physiological signals is sketched in [3], but heart activity only stands as an additional feature of a new human-computer interaction technique. Our interest, on the other hand, is from the start in human-*human* interactions.

We seek to use a game as a dedicated use case of physiological monitoring's influence over social interactions. We also want to explore how we could maximize user experience by integrating seamlessly the technology behind. As a matter of fact, the tabletop setup proposed in [3] requires additional gestures from users to perform actions as simple as hiding cards and in [13] each player needed a laptop. Yamabe and al. [16] used a projector to display the heartbeat directly on the gaming table, but, as in each other previous work, users still had to wear sensors. It is possible for technology to be even less intrusive, and we solution both kinds of artifacts.

Description of the system

The main idea is to propose a "sit and play" setup for 3 persons, where players would not have to endure any supplementary equipment before experimenting physiological sensing, and with no computers inside the game area in order to keep the genuine feel of board games.

Rather than using electrocardiography – that requires electrodes on the torso or on the wrists –, or other contact sensors, we turned to video analysis to record heart activity. To embed the visual feedback in the surroundings, we used projection instead of screens – this design choice also helped to present an asymmetrical biofeedback to players (Figure 4, middle).

While we cannot describe below all the technical aspects related to our system due to space limitation, we release our entire pipeline – summarized by Figure 2 – as an open-source software, for others to benefit from the technology[1].

Heart rate measures

Subtle color changes in a video could be amplified to the point that the variations of skin pigmentation occurring along each heartbeat become visible. To get real-time measures from 3 persons at the same time, we implemented an algorithm that takes values averaged over the face and that is computationally efficient. It was presented by [1], and enables a good accuracy even with regular webcams.

The optical measuring of the volumetric variation of an organ – such as the heart – is dubbed as photoplethysmography (PPG), hence this video-based method is called *remote* PPG. We successfully integrated various webcams into our workflow. We validated our implementation in a separate study by comparing remote PPG measures to a ground truth obtained with an electrocardiogram (ECG). Over 10 minutes recording sessions, the Pearson correlation varied between 0.30 and 0.81 – Figure 3, see also [4].

Spatial augmented reality

Spatial augmented reality merges the digital world into the physical world. It made the computers "disappear" in the eye of the players, helping physiological monitoring to become part of a traditional board game.

SAR was also a way to multiply the displays without the need of adding physical screens – tablets, laptops, . . . – to players' surroundings. For instance, since we wanted to compare whether or not the visual feedback of oneself heart rate would change game experience, we just had to craft display stands with two sides, onto which we projected either a heart rate or an idling animation (see Figure 4), instead of using 6 separate screens.

[1] https://github.com/jfrey-xx/PhysioBluffGame.meta

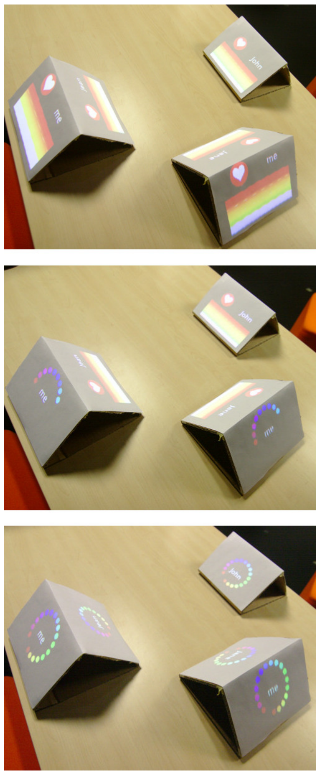

Figure 4: Our experimental conditions regarding heart rate (HR) visualizations. *Top*: HR visible by all players. *Middle*: HR visible by the others but not by self. *Bottom*: HR not visible.

The video projector was positioned in a top-down orientation 1.5m above the table. The resulting display surface was 1.2m by 0.75m. The visual feedback of the heart rate had two modalities. An icon shaped as a heart that was beating at the pace recorded by PPG, and beneath was a histogram plotting the BPM (beats per minute) of the previous 20 seconds. The names of the players were displayed on the stands' sides facing others – "me" on the side facing them, helping to raise both their presence and their social awareness. To obtain the desired visualization we used a framework developed in Processing[2] that could be easily grasped by game makers or artists[9].

All computations, for all 3 players, were done on a single computer, an Alienware Aurora R4 with an Intel i7-3820 processor, 8GB of RAM and a GeForce GTX 660 Ti graphic card running Kubuntu 14.04 operating system.

Pilot study

With the first iteration of our system, we wanted to investigate how users felt regarding the heart rate feedback and the setup. Our hypothesis is that while physiological computing enhance game experience, more stressful situations could arise if the feedback is asymmetric, not visible by self.

In this study we compared three different conditions of heart rate feedback: heart rate visible by all ("HR all"), heart rate visible by the others but not by self ("HR others"), heart rate visible by none (control condition, "HR none") – see Figure 4. We used a within-subject experimental design. The conditions were set for all 3 players of a group at the same time, and each condition occurred once. The order of the conditions was counter balanced between groups following a latin square – hence we recruited 6 groups.

We used a questionnaire inquiring about social presence to measure the main effect of our experimental design and collated players' spontaneous comments to gain further insight about the overall game experience.

Board game

We chose a friendly and casual board game known as "Coup" – edited by *Indie Boards and Cards*[3] – in its French version, "Complots". *Coup* possesses bluffing as one of the core elements of its gameplay. This is an incentive for players to use the physiological signals, since for the general public heart rate is strongly related to emotions. In *Coup* each player is given two random cards, each card representing a character, each character having a "power" – block or counter attacks, steal money, and so on. The goal is to "kill" the characters of the other players. There are various occasions to interact, and unless someone is "challenged" by an opponent, players never have to actually *show* their cards. These situations are most engaging for players. The pace is fast, one game lasts about 5 minutes.

Participants & Apparatus

18 participants took part in this study – 6 groups of 3 players, 5 females, 13 males, mean age 23.3 (SD: 6.9). Most of the participants knew each others beforehand. Half of them reported a previous use of physiological sensors, each time associated to sport or to medical activities.

To record players' faces, we used a set of 3 Sony PlayStation Eyes cameras hanging from the ceiling, slightly above the head. These webcams are cheap – around 10 dollars the unit at market price – and yet provided good images. We used a 640x480 resolution at 30 FPS and a custom Linux driver that directly fetches raw data (i.e. the Bayer matrix) to ensure maximum video quality.

Protocol

The participants came by 3 to play the card game. After they signed a consent form and filled a demographic questionnaire, they were taught the rules of the card game and

[2] https://processing.org/

[3] http://www.indieboardsandcards.com/

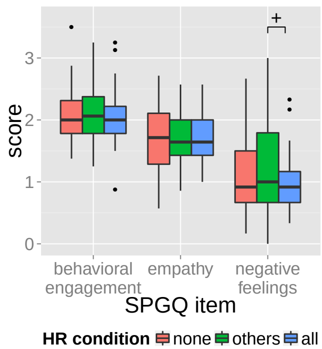

Figure 5: Results of the SPGQ questionnaire – tendency is marked with a "+" sign.

a "warm up" game took place. Once the players were confident they knew the rules, the SAR system was switched-on and the meaning of the visualization was explained to them.

Then one of the 3 conditions occurred, participants playing on their own. After about 10 minutes and a game ended the participants filled a questionnaire related to social presence (see next section). There were on average 2 games per condition.

This step was repeated twice, for the 2 other feedback conditions. After the completion of the 3 conditions, participants filled one last questionnaire to sense their general feeling about the setup. Overall, a session lasted approximately 90 minutes.

Measures

Our main metric is composed by the questionnaire given after each condition occurred, the Social Presence in Gaming Questionnaire (SPGQ) [8]. SPGQ is rated on 5-points Likert scales and contains 21 items in total. Its aim is to qualify social presence between players on three different axis: "empathy" (e.g. "When the others were happy, I was happy"), "negative feelings" (e.g. "I felt revengeful") and "behavioral engagement" (e.g. "The others paid close attention to me").

Besides those measures, aimed at comparing our experimental conditions, we also noted participants' reactions while they were playing in order to gather more insights about what they experienced in regards to the biofeedback. To do so, the experimenter wrote down the exchanges between players that mentioned explicitly the displays or their heart activity.

Results

We used a Friedman test and post-hoc pairwise Wilcoxon tests adjusted for multiple comparisons with false discovery rate to compare our 3 heart rate feedback conditions ("HR none", "HR others", "HR all"). There was no significant differences in the SPGQ, although we found a tendency for the "negative feelings" score ($p \approx 0.1$) between "HR others" and "HR all" conditions. There was more negative feelings reported in "HR others" compared to "HR all" condition – 1.19 *vs* 1.06 (SD: 0.87 *vs* 0.64), see Figure 5.

At the end of the pilot study we asked our participants their opinions about each experimental condition and about the technical aspects of the setup, using 5-points Likert scales ranging from 0 "I did not like at all" to 4 "I liked a lot". The "HR all" condition was slightly favored over the "HR others" condition – 2.83 *vs* 2.78 (SD: 0.79 *vs* 1.06), and the condition with no HR feedback was ranked last – mean: 2.44 (SD: 0.86). About the technical aspects of the setup, participants praised the SAR display – 3.28 score, SD: 0.89, and were satisfied with the remote PPG heart rate measure – 2.89 score, SD: 0.96.

A selection of comments referring to the heart rate feedback that players said to each other is presented in the side bar page 6. The proportion of references to emotions or decision processes, to events in-game or out-game, is representative of what we annotated during the different games.

As for *how* the physiological feedback was utilized, we observed two different kinds of players, roughly in equal proportions. First, the players that did not use explicitly the heart rate display during the game. Even when they liked to see it, they did not use this information while interacting with other players. During informal inquiries, those players reported that the provided heart rate display was hard to interpret. The second profile is among players that did use the feedback; participants that knew beforehand the game and the rules were immediately attracted by the heart rate feedback and remained the most enthusiast throughout the game.

Players' comments during the game

– "Your rate is really high now, it's because you're upset!"
– "It's stressful because I don't see my heart!" (*HR others* condition)
– "Look at how his heart's beating, he's going to make a mistake I think..."
– "Damn, I got a huge spike, it's because I won, I killed someone!"
– "You're a bit fast, you look stressed!"
– "I see your plot and I see you bluffing."
– "We're seeing your plot, don't go crazy!"
– "I don't own the game anymore, I cannot bluff..."
– "You saw how it went up suddenly?" / "Yes, it's because I was happy."
– "He said he liked her, and his heart increased..."
– "You're totally busted, I saw it, it increased!"

Discussion

Players had a tendency to report more negative feelings in the SPGQ questionnaire when others could see their heart rate but when themselves could not. From direct observation, it seems that players used this asymmetry to "tease" themselves, giving false or exaggerated feedback to the one that could not see by herself or himself the real heart rate. Sharing the information evenly should prevent social stress – unless of course a game designer *wishes* to create a very competitive gameplay. These findings only partially go along our hypotheses since players still preferred an asymmetrical feedback rather than no HR feedback at all when they were asked to rank explicitly the experimental conditions at the end of the study.

Concerning the utilization of the heart rate display, we did not give absolute values to avoid a too intrusive feedback, and we used the same scale for all players in the "history" plot to adapt to all metabolisms. These choices may have prevented some players to comprehend well the information, but dynamic representation of low-level physiological signals is still an open question at the moment [2]. Hence, other visualizations should be investigated as well as other feedback modalities, such as sounds. The profile of players that used extensively the biofeedback suggests that physiological signals could be used to add another layer to an existing game, especially for experts.

Players often associated heart rate to emotions, although in fact this is *one* among many different traits that could be inferred from heart rate [7]. This is easily explained by the common knowledge surrounding heart activity and by cultural references. Still, some participants did not hesitate to interpret various – and sometimes random – events in light of the heart rate feedback. During exchanges between players, most often the firsts to speak were watching others' signals and wanted to playfully bother their opponents.

Conclusion & Future works

We presented a framework that combined remote heart rate sensing and projection to bring anew an existing board game. We observed that players did use the physiological feedback over the course of the games, suggesting that it could improve the richness of the interactions. Thorough examinations are needed before we could draw solid conclusions about how the gaming experience is altered; during our study we sensed how a discrepancy between what is recorded and what is shown to users could lead to stress, when one's heart rate is seen only by the *other* players.

The visual feedback was mapped to simple objects. While this projection was already sufficient to obtain a game room where anybody, at anytime, could take a seat and start to play, one may venture further into spatial augmented reality. Heart rate could be projected on board game elements or on more detailed objects, small avatars for example, e.g. [5]. As for remote sensing, our system can accommodate many webcams. We were able to incorporate the Microsoft Kinect 2, which encompasses several persons at once thanks to its wide-angle lens – ideal for a "blackjack" placement.

In the end, game designers can integrate heart rate measurements directly to the gameplay and develop a new game system. For example, in a card game a special picture could mask one's heart rate – it would be up to the opponents to decide if the player wants to hide something. . . or just to make them believe so. A common and shared space, thanks to SAR, could also favor collaboration or competition over physiological states. The possibilities are limitless, and may be explored by the players themselves. As matter of fact, not all the modifications observed by *our* players were related to actual physiological changes. Some players rightfully reported that the values changed when the webcam was "seeing the hair". Attempting to deceive opponents is one way to play with physiological signals.

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